Senior Thesis

An Examination of Griggs Reservoir, Upper Arlington, Ohio: Capacity yield and sedimentation data

by
Jason Brown
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Dr. Lawrence A. Krissek

Abstract

Interpreting sediment yields due to environmental change requires synthesis of the available evidence of sedimentation relating to the impact imposed by human activity. Long term accurate records of sediment transport are scarce for most areas of the world. The bulk of sediment input to reservoirs is from periodic storms and accompanying flood activity. Sedimentation in lakes and reservoirs received little systematic attention in the past. Eventually sediment yields decline in response to the introduction of soil conservation measures. Mahmood (1987) has estimated that major reservoirs of the world are currently losing storage capacity at a rate of 1% of gross capacity per year through sedimentation.

Introduction

Sediment deposition occurs continuously and simultaneously with erosion in fluvial systems. Sediment, as suspended load, travels at the same velocity to that of flowing water. Sediment, also as bedload, travels along the bottom in a river system at a slower velocity. Sediment load in rivers generally increases as a power function of discharge. (Mahmood, 1987) Therefore, larger river systems transport suspended sediment in quantities that are much greater than the suspended load carried by smaller river systems. On all rivers, suspended sediment volumes vary between flood stage discharge and low flow discharge stage.

Reservoirs serve to store water for humankind's survival. Along with the water in rivers is, however, sediment. The impact sediment has as it accumulates in reservoirs reduces their capacity for storing water. Over time, the reservoir cannot effectively store volumes of water equivalent to the reservoirs original capacity. The amount of sediment deposited in a catchment is referred to as sedimentation yield. "Sediment yield is defined as the total outflow from a catchment or drainage basin, measured at a cross-section reference in a specified period of time." (Butcher and others, 1993) Sediment transported in a fluvial channel is deposited upon reaching quieter waters in a lake or reservoir. Over time, a record of sediment accumulation since the construction of the impoundment is developed. Overburden of younger sediment upon older sediment will compact the underlying sediment, thereby decreasing the volume of the older sediment. Although compaction of sediment occurs, the impoundment will still have a net loss of volume.

Examination of deposits in reservoirs, has identified changes in sediment yield linked to factors such as catchment land use changes, catastrophic floods, and the rise of urbanization. Floods caused by storms have major impacts on sediment transport to a catchment. Bulk sediment flow commonly occurs during a limited number of high rainfall events. Land use changes decrease the quality of runoff while increasing sedimentation in drainage catchments. In rural areas, clearing of vegetation is one of many contributors to erosion of soil and subsurface materials. Upon deposition, this material becomes sediment. Awareness of the problem of soil erosion continues to increase, but more soil conservation practices need to be implemented. A study in Coventry, United Kingdom, (Charlesworth and Foster, 1993) has profiled the changes that can occur in urban lakes. Both natural and artificial reservoirs were first built in rural areas, but rural areas undergoing conversion for a catchment structure were shown to be most sensitive to erosion. Any disturbed of soil was easily removable by water or wind.

Humankind is eager to change the land as the need for more urban space and development continues. Development of rural areas directly increases the discharge of sediments in rivers. Scientists need to consider the degree to which the sediment loads of the world's rivers have changed in response to human activities. Problems arise with land degradation especially with the expansion of agriculture. Additional projects, including housing estates, industrial buildings, roads, landfill sites, and powerstations may increase sediment delivery and decrease water quality into the reservoir itself.

Not all of mankind's activities increase sediment yield. Once a catchment is built, it can significantly decrease and may, in some cases, totally eliminate the sediment load downstream (Mahmood, 1987). A major river affected in such a way is the Colorado River, USA. On the Colorado River, Hoover Dam is effectively reducing sediment transport downstream as documented by Mead and Parker (1985) sediment discharge has declined from 135 million tons per year to the current values of 0.1 million tons per year. Reducing sediment discharge downstream exemplifies, on a smaller scale, mankind's effect with the construction of Griggs Reservoir. However, sediment discharge will not be discussed in this paper.

After a catchment has been built, a sedimentological evolutionary path begins. Griggs Reservoir is filled by flow from river systems within the watershed of the Scioto River. Therefore the general series of processes that happen within any reservoir can be anticipated to influence Griggs Reservoir. Figure 1 shows, in the Piedmont Region of the Eastern USA, spatial variations of suspended sediment yields. This curve shows the change in sediment yield over time with land use. Of significance is the sharp dis-equilibrium in sediment yield just prior to urbanization. A large spike indicates the immediate effect caused by deforestation and slow rate of which erosion control measures become effective. As time passes, sediment yields return to natural levels. Even cropping has moderate effects on sediment yields; however, land is continuously being turned over to agriculture. A similar pattern of development occurred in Upper Arlington during the beginning of this century, during the time of construction and early history of Griggs Reservoir.

The impact of sedimentation in catchment structures is a continuous problem. In many cases, the lack of reliable long-term records limit for study of the life cycles of reservoirs (Walling, 1997). The oldest records for Griggs Reservoir date back to 1906 and for most other reservoirs records only date back to 1920's to 1930's. An associated problem is the lack of accurate estimates of annual sediment loads. An understanding of sediment yields and sedimentation rates is aided by the similar cycle of activities occurring in all artificial impoundments. Our knowledge of other reservoirs and their sedimentation rates, can be used to help interpret the infilling history of sedimentology of Griggs Reservoir.

Materials and Methods

The data and methods used were intended to calculate average rates of deposition from historical topographic surveys of Griggs Reservoir. The most efficient way to do these calculations were to use Microsoft Excel spreadsheet and graphing software. The data consisted of water depth surveys conducted by the Columbus Division of Water between 1906 and 1994, taken at approximately fifteen year intervals.

Water depth surveys are available for the years 1906, 1935, 1951, 1964, 1986, and 1994 with the depths given for sixty-five cross-sections along the length of the reservoir. The data sets 1935, 1964 and 1994 are not complete, and is the basis for this paper.

Sedimentation rates were calculated by determining the water depth change at each point along each cross-section from 1935 to 1964 and from 1964 to 1994. These differences were then divided by the number of years they span to determine the average sedimentation rate at each location These intervals correspond to twenty-nine and thirty years, respectively. Each difference in elevation for each column is divided by the number of years. The result was an assumed rate of sedimentation in feet per year.

Because this data set produced a large number of sedimentation rates, presentation and interpretation of the results were simplified in several ways. First the average sedimentation rate for each cross-section for each of the two time intervals was calculated in order to examine large scale trends along the length of Griggs Reservoir. Second, the maximum sedimentation rate for each cross-section for each of the two time periods was selected, also with the goal of defining large scale trends along the length of Griggs Reservoir. Third, the cross-channel distribution of sedimentation rates was examined for a subset of the 65 cross-sections, in order to determine if deposition was consistently focused in one part of the channel.

The average sedimentation rate and the maximum sedimentation rate for each time interval for each cross-section were plotted against cross-section number. These figures and their meaning will be discussed later in the paper. The selected subset of cross channel profiles of sedimentation rates was also plotted, and will be presented and discussed later.

Data

The original data set consisted of station number, cross-section number, distance from eastern shore in feet along the cross-section, and elevation in feet for the years of 1935, 1964, and 1994. Calculations using the original data created derived parameters. The derived parameters include sedimentation rate in feet per year for 1935-1964 and sedimentation rate in feet per year from 1964-1994, average and maximum sedimentation rate in feet per year for 1935-1964, from which average and maximum sedimentation rates in feet per year were determined for 1935-1964 and 1964-1994. The first sheet of plots of Griggs cross-section data shows the average sedimentation rate for the cross-section for 1935-1964, plotted as a function position along Griggs Reservoir. The second sheet shows the maximum sedimentation rate for the cross-section for 1935-1964, again plotted versus position along Griggs Reservoir. This continues for the period from 1964-1994 average and maximum sedimentation rates for the 65 stations along Griggs Reservoir. The following pages show the stations with the cross-channel distribution of sedimentation rates for 1935-1964 and 1964-1994 for cross-sections 1, 3, 6, 10, 20, 30, 40, 50, and, 60. These graphs will be presented in this order.

Discussion

Data sets for average and maximum sedimentation rates for the times 1935, 1964, and 1994 along Griggs Reservoir were plotted to search for general trends of sedimentation. Large scale trends are seen in the average sedimentation rates for the two times 1935-1964 to 1964-1994.

First, average sedimentation rates for the two time intervals, 1935-1964 and 1964-1994 are plotted for all 65 stations. The general patterns of these curves are similar, with relatively constant average sedimentation rates upstream of the station and increasing sedimentation rates downstream from station. For the time 1935-1964, large rates of sedimentation occurred from Station 1 to approximately Station 30. Further away from the dam, at higher station numbers, sedimentation rates were low. For the time period 1964-1994, sediment deposition still occurred in the manner described previously, but sedimentation rates were lower. At Station 1 from 1964-1994, a steep spike shows the average rate of sedimentation increase compared to the previous time period of Griggs Reservoir. Suspended sediment from upstream is depositing at Station 1 where slower quiet water resides. The decrease in average sedimentation for 1964-1994 time period upstream of Station 1 is the watershed adjusting to conservation practices within or around Griggs Reservoir in Upper Arlington at this time.

Second, for the same time intervals, the maximum sedimentation rate in each cross-section was plotted for each 65 stations. Although more erratic looking than the plots of average sedimentation rates, also show an upreservoir decrease in maximum sedimentation rates. For 1935-1964, the maximum sedimentation rate steadily decreased from Station 1 to approximately Station 33. Upstream from Station 33, the maximum sedimentation rate balance became relatively constant. The plot of maximum sedimentation rate for 1964-1994, is very erratic. What is important is that there is no discernible pattern of maximum x.sedimentation rates along Griggs Reservoir. The pattern is now relatively steady almost a century later after reservoir construction. The large spikes may be due to human error during measuring, caused by debris on the bottom of the channel, by the recurrence intervals of large flood activity, or by mislocation of measurement sites from one survey to the next.

The third set of plots shows cross-channel distributions of average sedimentation rates for a subset of the 65 cross-sections. The first set of graphs, for 1935-1964, shows a variety of cross-channel sedimentation rate patterns along the length of Griggs Reservoir. Station 1 shows sedimentation was the greatest in the middle of the channel width. At Stations 3, 6, and 10, maximum sedimentation shifts from the center toward the shores. At Stations 20, 30, 40, 50, and 60, no consistent patterns in the distribution of sedimentation rates can be seen. The cross-channel profiles of sedimentation rates from 1964-1994 show stronger and more consistent trends. Station 1, 3, 6, and 10, show a bimodal distribution, with maximum sedimentation occurring along each side of the reservoir. The sedimentation peaks are very large, especially for Stations 1 and 3. This pattern likely repeats for Stations 20 and 30, but there are not enough data points to show the distribution well. At Stations 40 and 50, the bimodal sedimentation distribution reappears, with maximum sedimentation approaching closer to the shores than for any of the other stations for either 1935-1964 or 1964-1994.

Sedimentation rates for the two time periods vary because of the local activity of urban development and the details of weather patterns. Other patterns of sedimentation along the length and across the channel are due to the dynamics of the river itself.

Conclusion

Sedimentation in all rivers is an inevitable fact. The idea for humankind to be able to prevent nature from infilling our reservoirs eludes our technological abilities. Tactful methods of erosion during urbanization of rural land may initially decrease a short and intense amount of deposition, however, as years and decades pass sedimentation will accumulate on the bottoms of reservoirs. As we learn understand processes of sedimentation in reservoirs, the better our planning for site location in choosing further reservoir construction localities. The study of sedimentation rates of Griggs Reservoir compared between two time periods, presents the general occurrence in reservoirs all over the world.

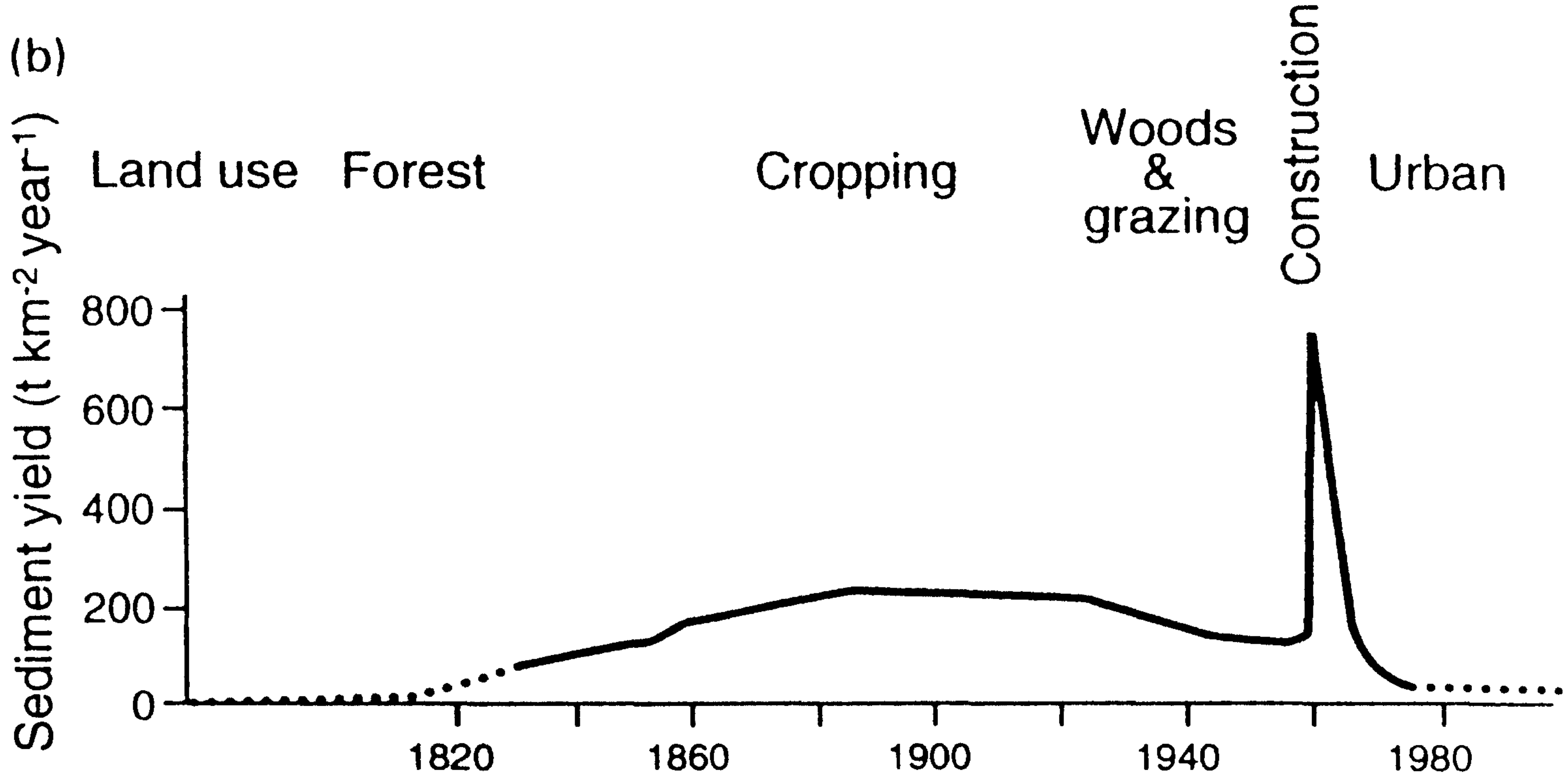
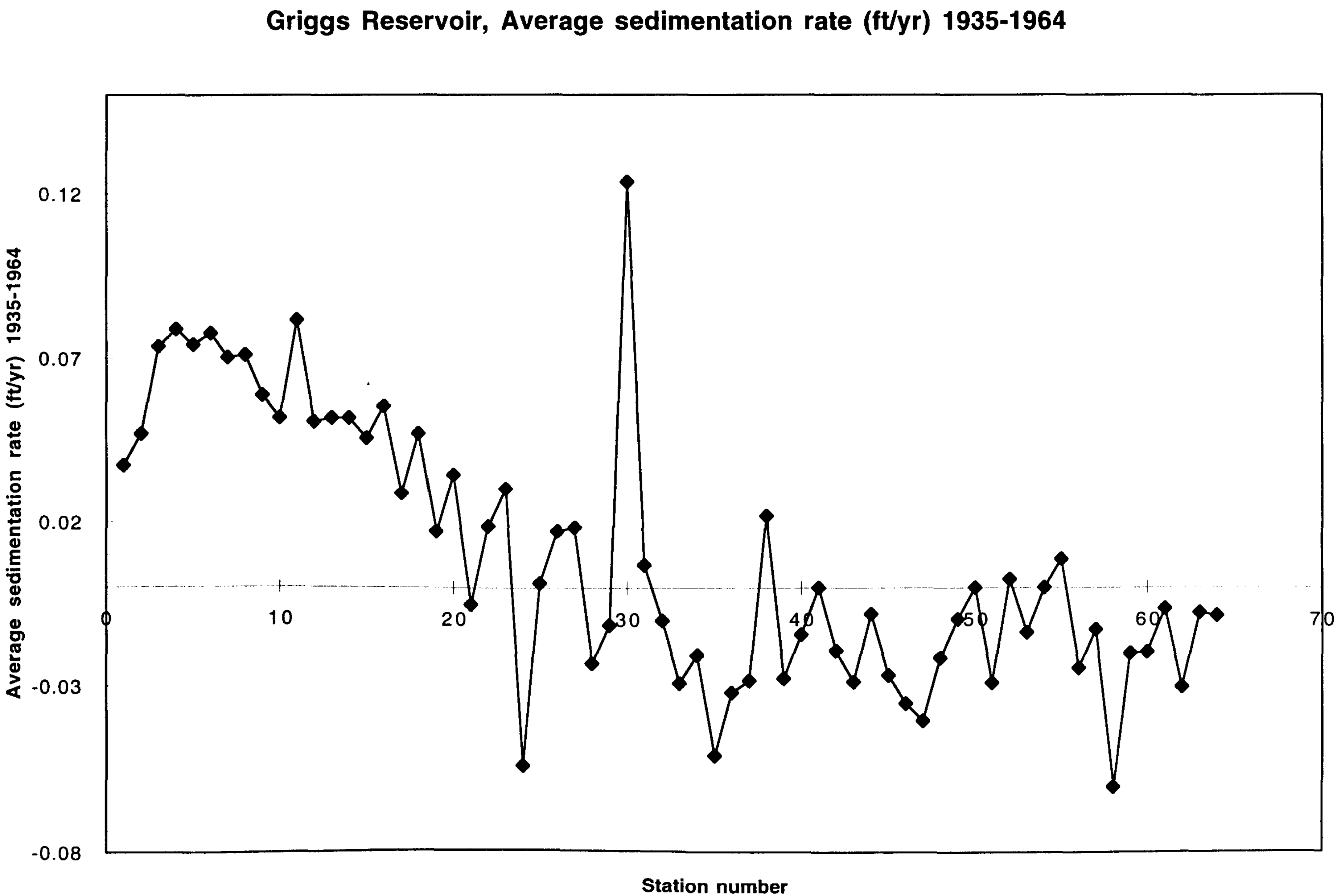
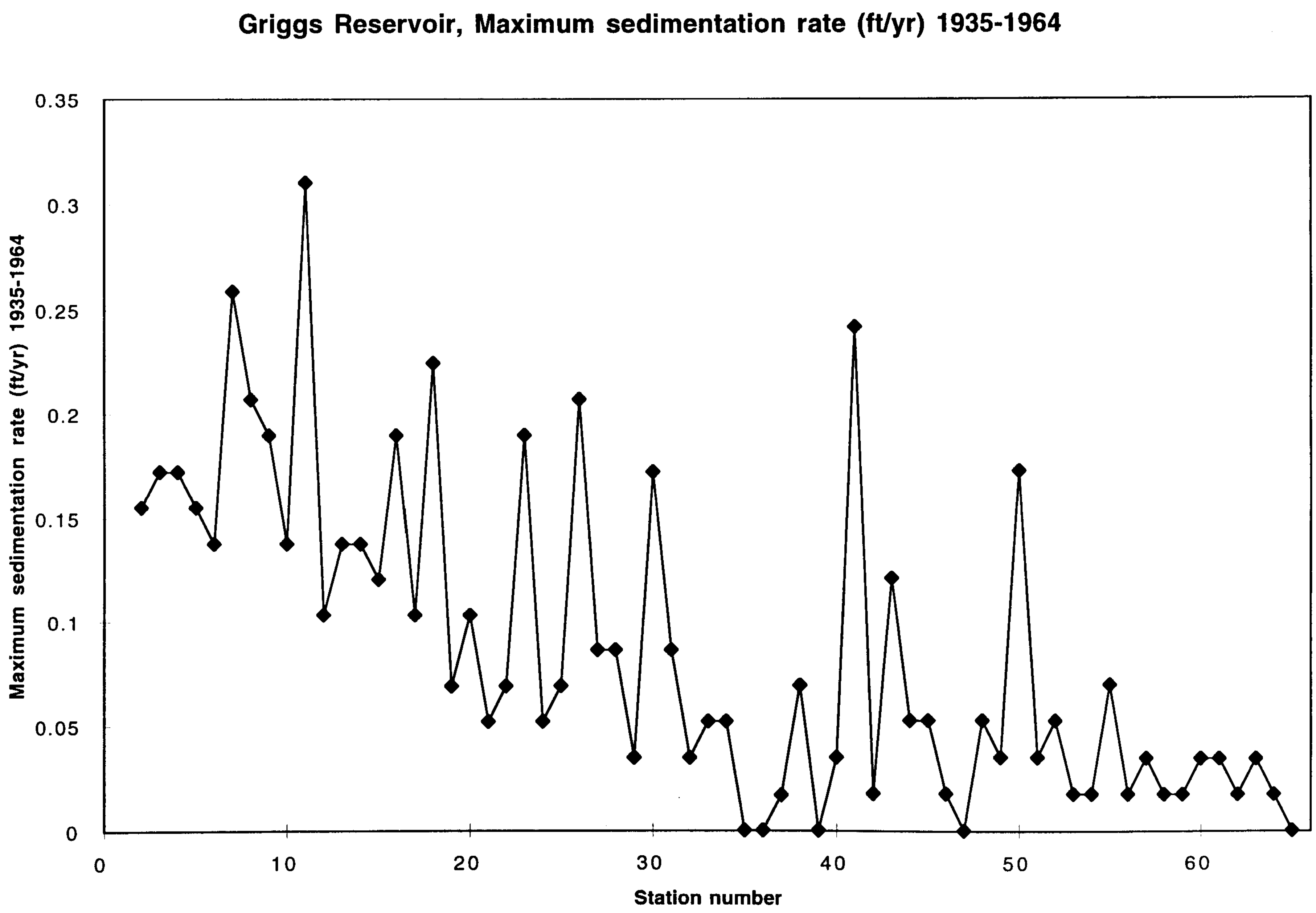


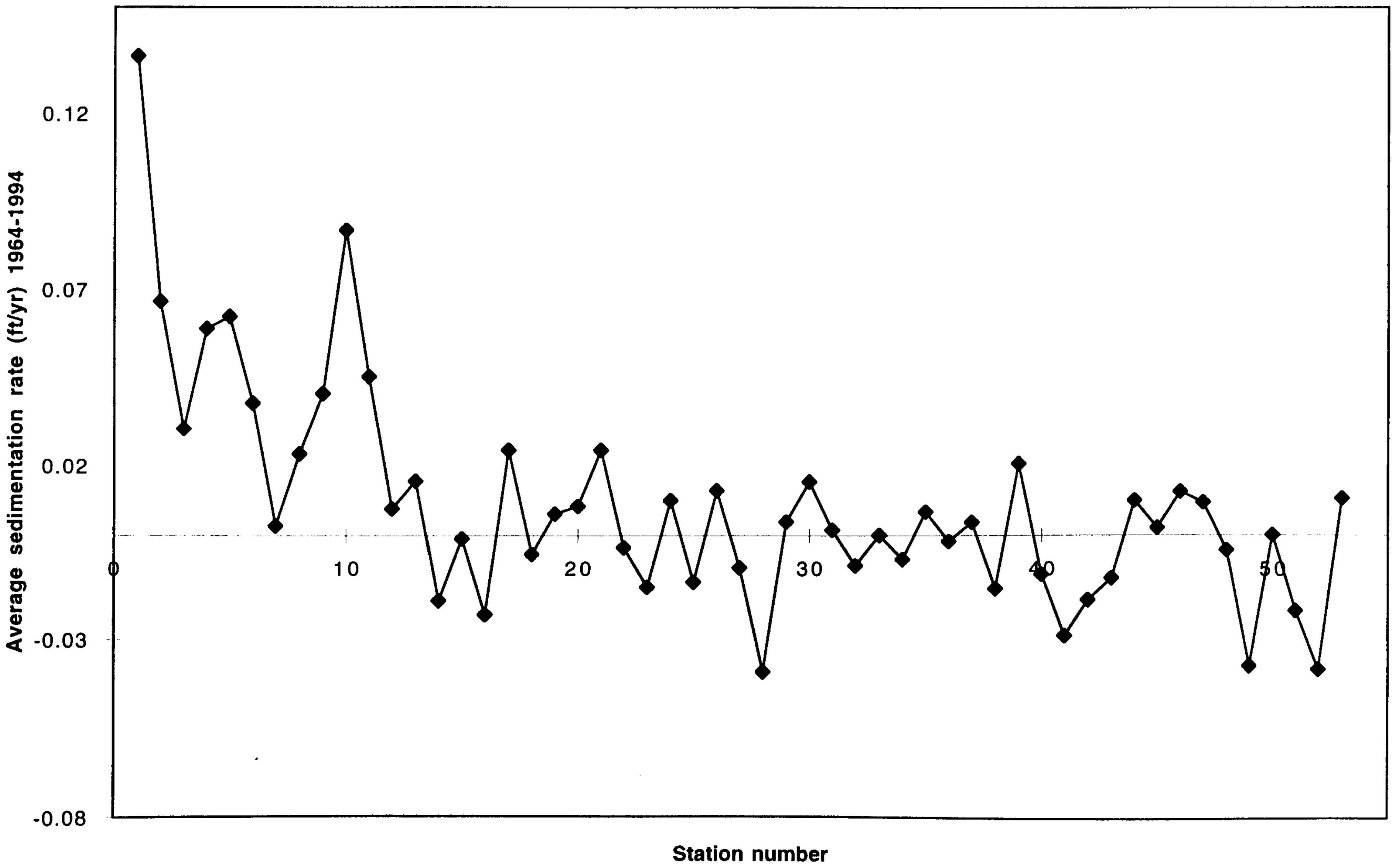
Fig. 3 Spatial variation of suspended sediment yields in the Piedmont Region of the Eastern USA (a) and a reconstruction of the record of suspended sediment yields in the region based on space-time substitution. (Based (a) on Wolman & Schick (1967) and (b) on Wolman (1967).)

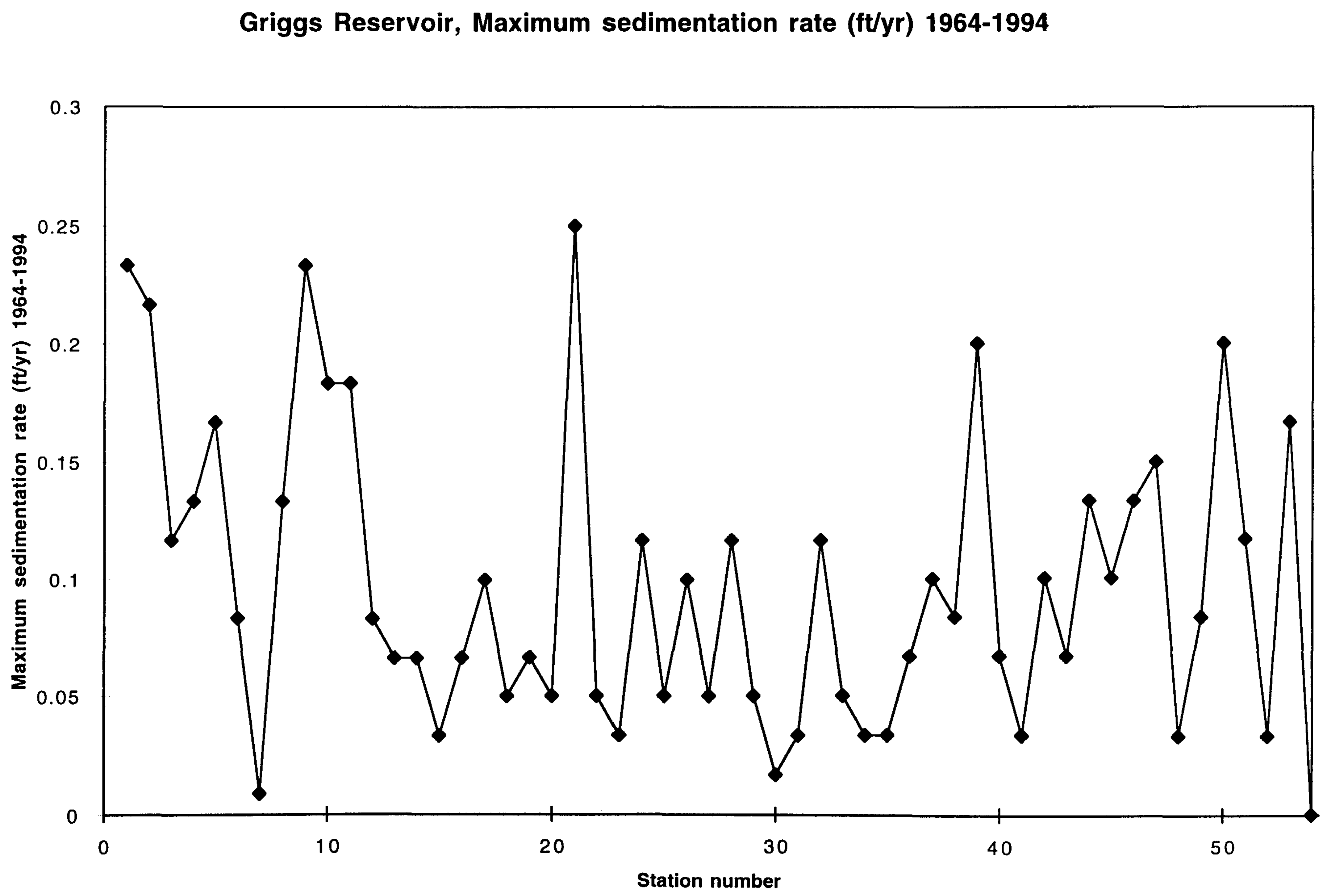
Plots of Griggs cross-section data


Griggs Reservoir, Average sedimentation rate (ft/yr) 1935-1964
0.12
0.07
0.02
-0.03
-0.08
Average sedimentation rate (ft/yr) 1935-1964
0
10
20
30
40
50
60
70
Station number


Griggs Reservoir, Maximum sedimentation rate (ft/yr) 1935-1964
Maximum sedimentation rate (ft/yr) 1935-1964
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10
20
30
40
50
60
Station number

Griggs Reservoir, Average sedimentation rate (ft/yr) 1964-1994



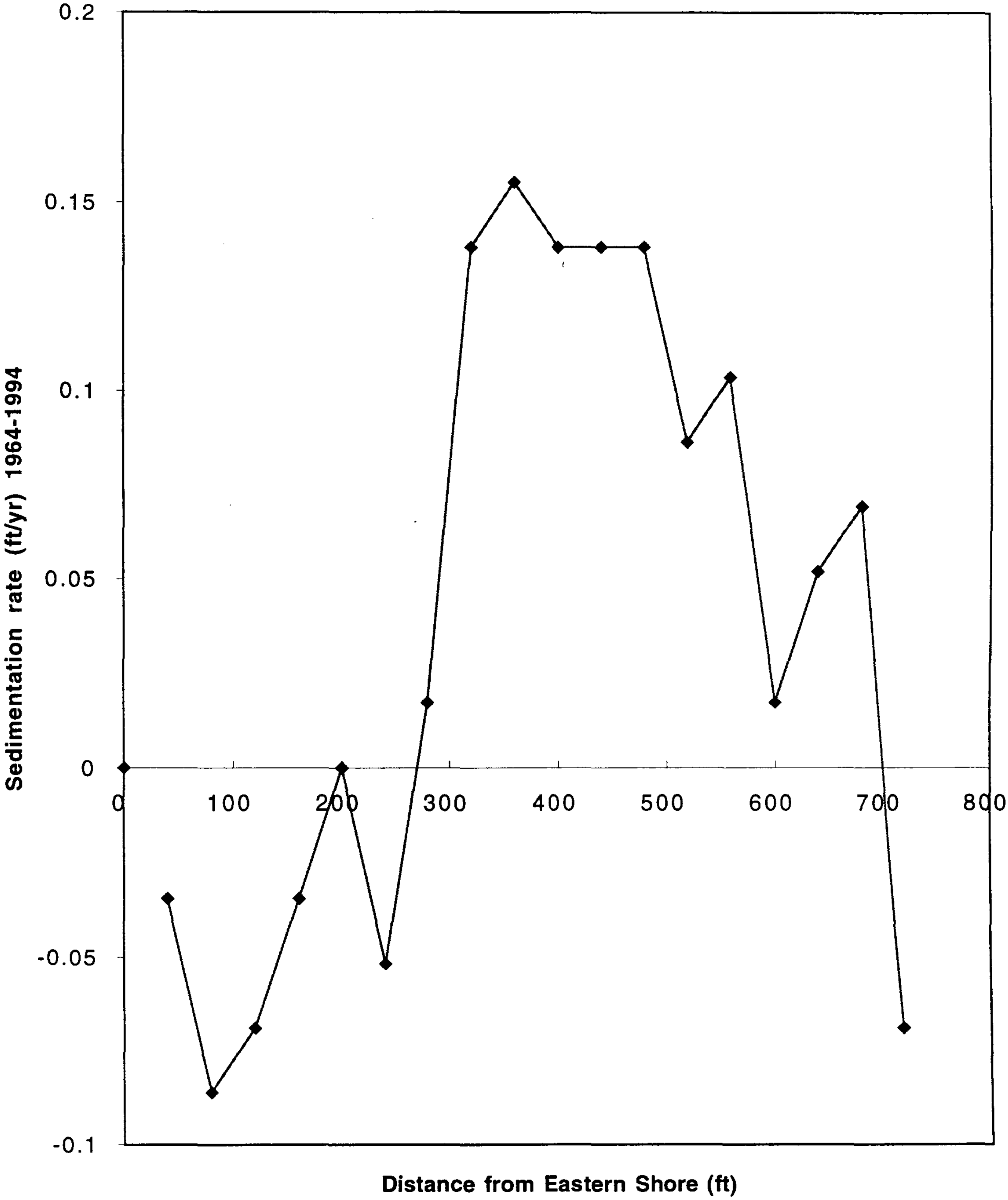


Griggs Reservoir, Maximum sedimentation rate (ft/yr) 1964-1994
Maximum sedimentation rate (ft/yr) 1964-1994
0.3
0.25
0.2
0.15
0.1
0.05
0
0
10
20
30
40
50
Station number

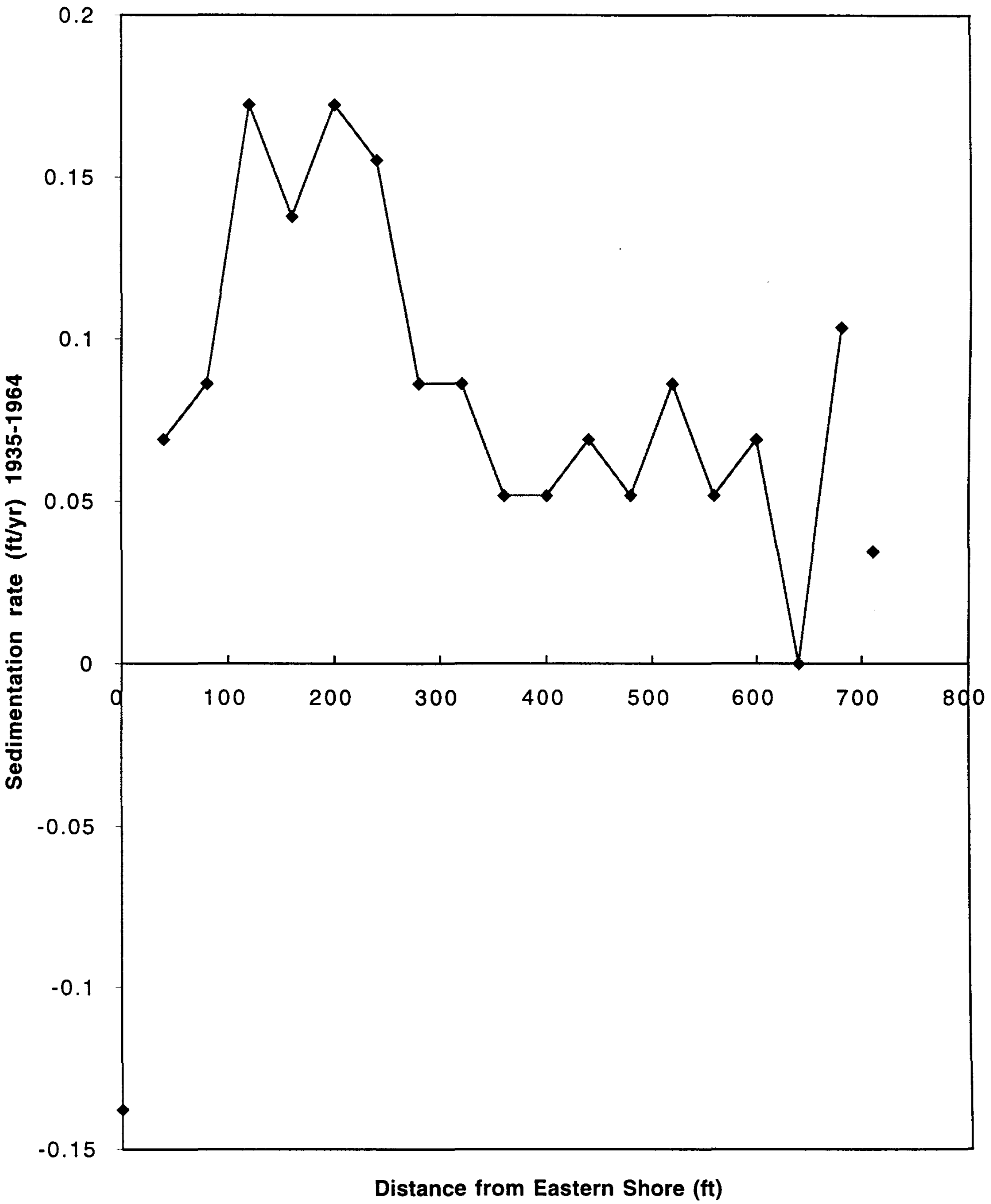
station	Max. sed. Rate 35-64	Max. sed. Rate 64-94	Avg. sed. Rate 35-64	Avg. sed. Rate 64-94
	0.1551724	0.2333333	0.0372051	0.1361111
2	0.1551724	0.2166667	0.046798	0.0666667
3	0.1724138	0.1166667	0.0735027	0.0303922
4	0.1724138	0.1333333	0.0786638	0.0588889
5	0.1551724	0.1666667	0.0740365	0.0622222
6	0.137931	0.0833333	0.0775862	0.0377778
7	0.2586207	0.0086207	0.070197	0.0026083
8	0.2068966	0.1333333	0.0709939	0.0233333
9	0.1896552	0.2333333	0.0586207	0.0404762
10	0.137931	0.1833333	0.0517241	0.0869048
11	0.3103448	0.1833333	0.0816092	0.0452381
12	0.1034483	0.0833333	0.0505747	0.0076293
13	0.137931	0.0666667	0.0517241	0.0155556
14	0.137931	0.0666667	0.0517241	-0.019048
15	0.1206897	0.0333333	0.0455665	-0.0011282
16	0.1896552	0.0666667	0.0554187	-0.023077
17	0.1034483	0.1	0.0287356	0.0242424
18	0.2241379	0.05	0.0471264	-0.005556
19	0.0689655	0.0666667	0.0172414	0.0060606
20	0.1034483	0.05	0.0344828	0.0083333
21	0.0517241	0.25	-0.005305	0.0242424
22	0.0689655	0.05	0.0186782	-0.003704
23	0.1896552	0.0333333	0.0301724	-0.015152
24	0.051724	0.116667	-0.054377	0.01
25	0.0689655	0.05	0.00132626	-0.013636
26	0.206897	0.1	0.017241	0.012821
27	0.086207	0.05	0.018391	-0.009524
28	0.086207	0.116667	-0.022989	-0.039286
29	0.034483	0.05	-0.011494	0.003846
30	0.1724138	0.0166667	0.1235632	0.0153846
31	0.086207	0.033333	0.006897	0.001389
32	0.034483	0.116667	-0.010142	-0.008889
33	0.051724	0.05	-0.029038	4.08E-19
34	0.051724	0.033333	-0.020525	-0.007018
35	0	0.0333333	-0.050903	0.0066667
36	0	0.0666667	-0.031897	-0.001852
37	0.0166667	0.1	-0.028333	0.0037037
38	0.0689655	0.0833333	0.0217786	-0.015625
39	0	0.2	-0.027778	0.0205882
40	0.0344828	0.0666667	-0.014368	-0.011458
41	0.2413793	0.0333333	2.45E-18	-0.028889
42	0.0172414	0.1	-0.019397	-0.01875
43	0.1206897	0.0666667	-0.028736	-0.0125
44	0.0517241	0.1333333	-0.008114	0.01
45	0.0517241	0.1	-0.02682	0.0020833
46	0.0172414	0.1333333	-0.035441	0.0125
47	0	0.15	-0.040568	0.009375
48	0.0517241	0.0333333	-0.021552	-0.004444
49	0.0344828	0.0833333	-0.009698	-0.036905
50	0.1724138	0.2	0	0
51	0.0344828	0.1166667	-0.029095	-0.021429
52	0.051724	0.033333	0.002463	-0.037879
53	0.017241	0.166667	-0.013793	0.010417
54	0.017241	no data	0	---
55	0.0689655	no data	0.0086207	---

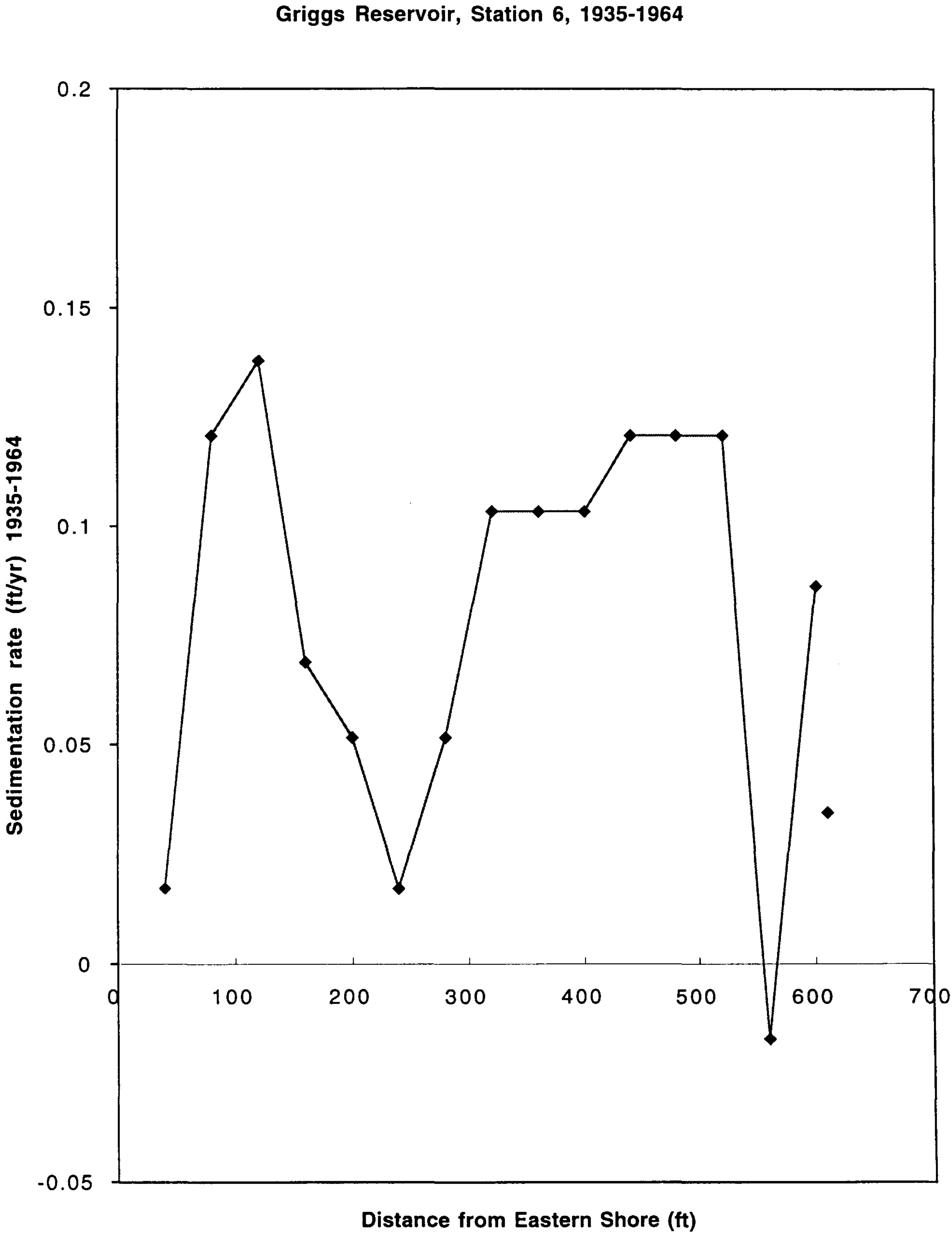
56	0.017241	no data	-0.024631	---
57	0.034483	no data	-0.012931	---
58	0.017241	no data	-0.060345	---
59	0.017241	no data	-0.020115	---
60	0.0344828	no data	-0.019704	---
61	0.034483	no data	-0.006466	---
62	0.017241	no data	-0.030172	---
63	0.034483	no data	-0.007663	---
64	0.017241	no data	-0.008621	---
65	no data	no data	---	---
			Average	Average
			0.00971331	0.008673745

Griggs Reservoir, Station 1, 1935-1964

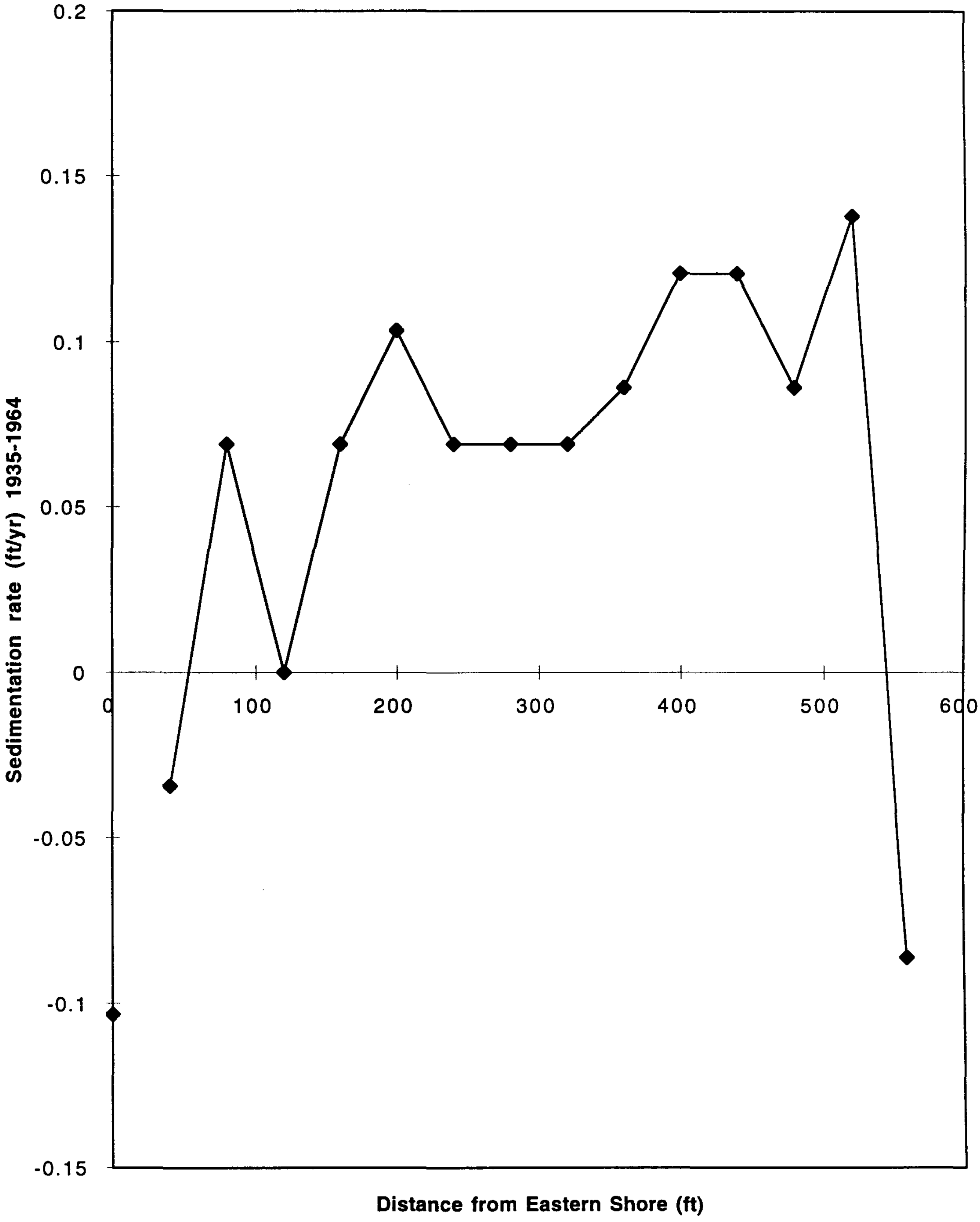


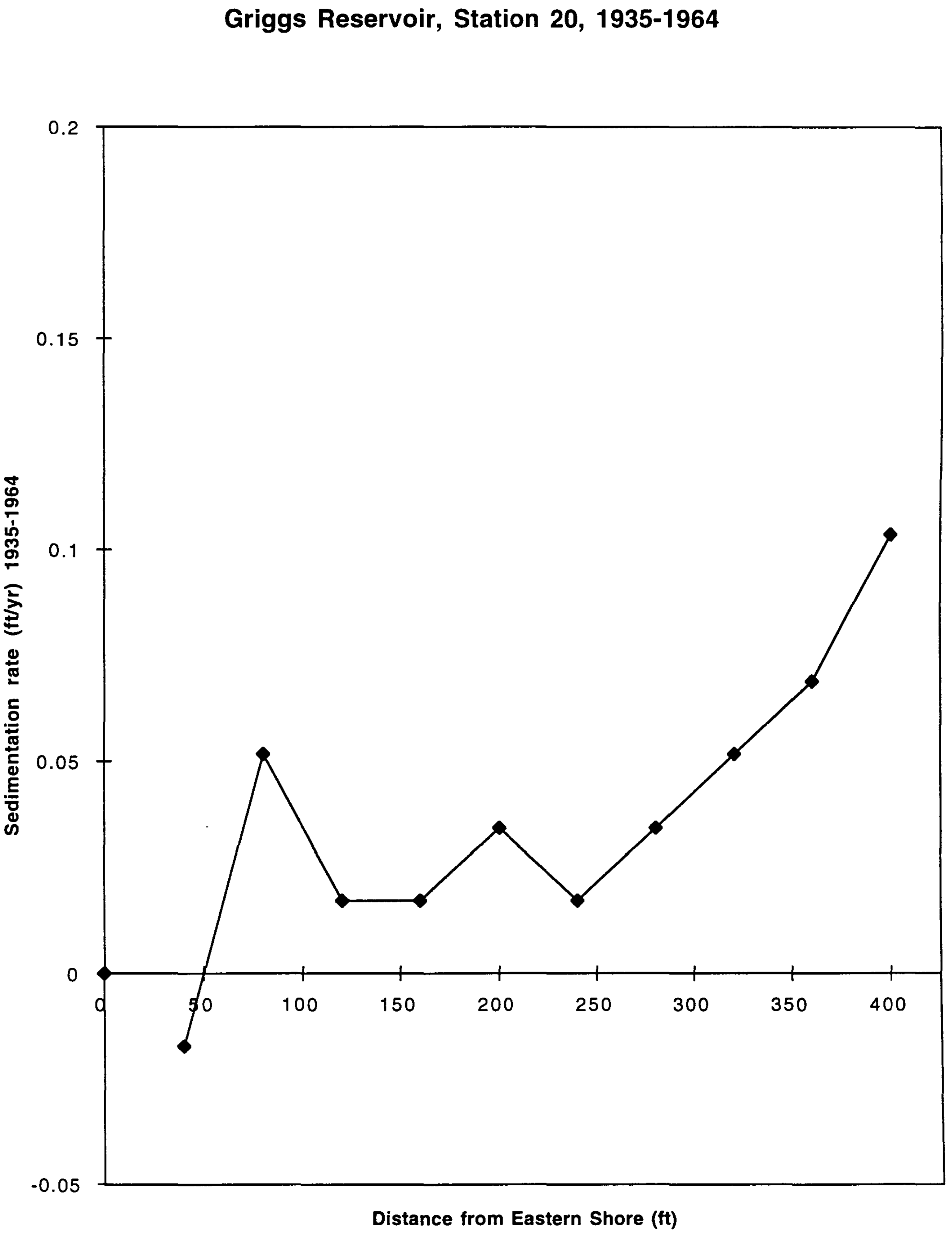
Griggs Reservoir, Station 3, 1935-1964

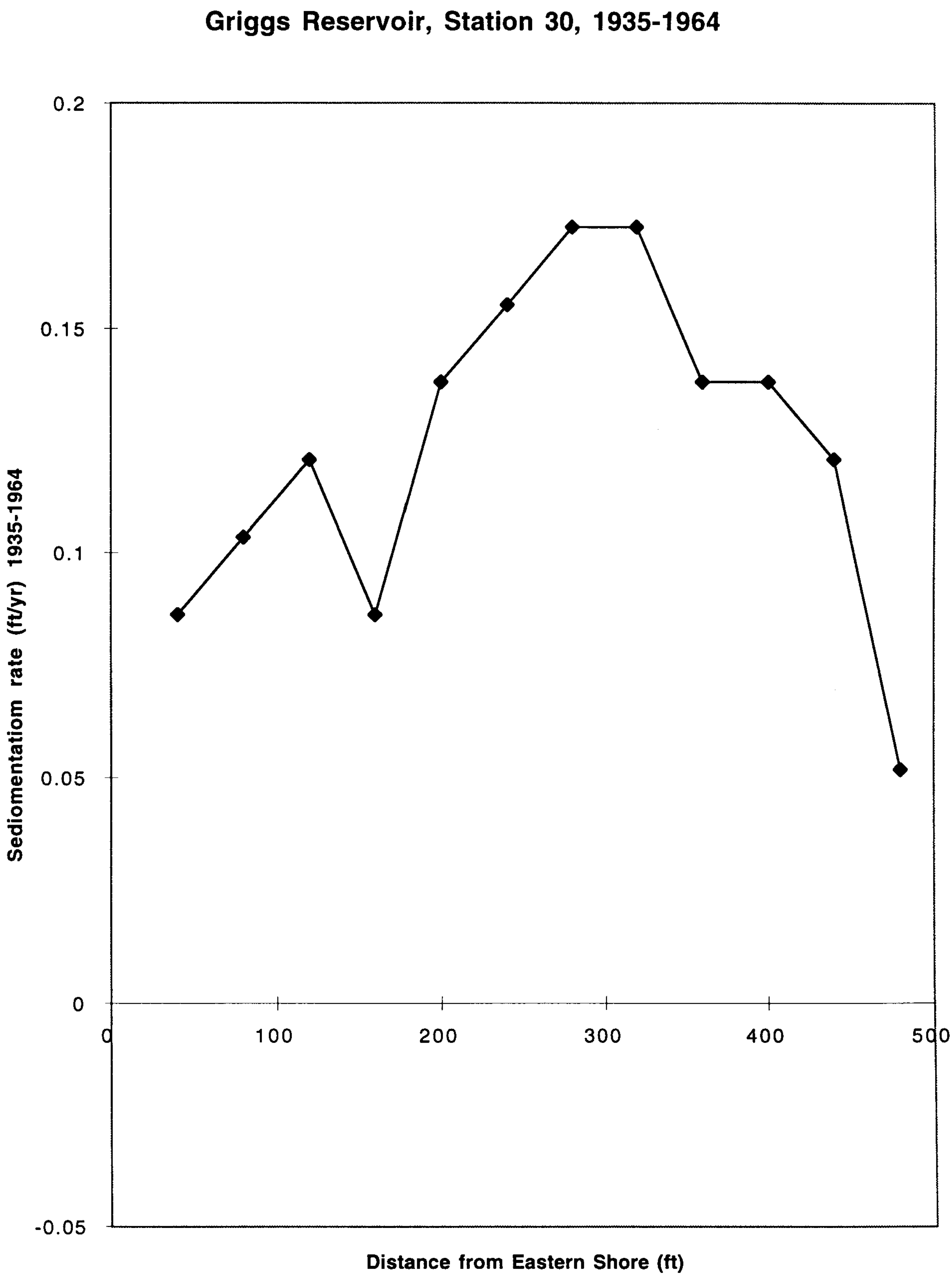


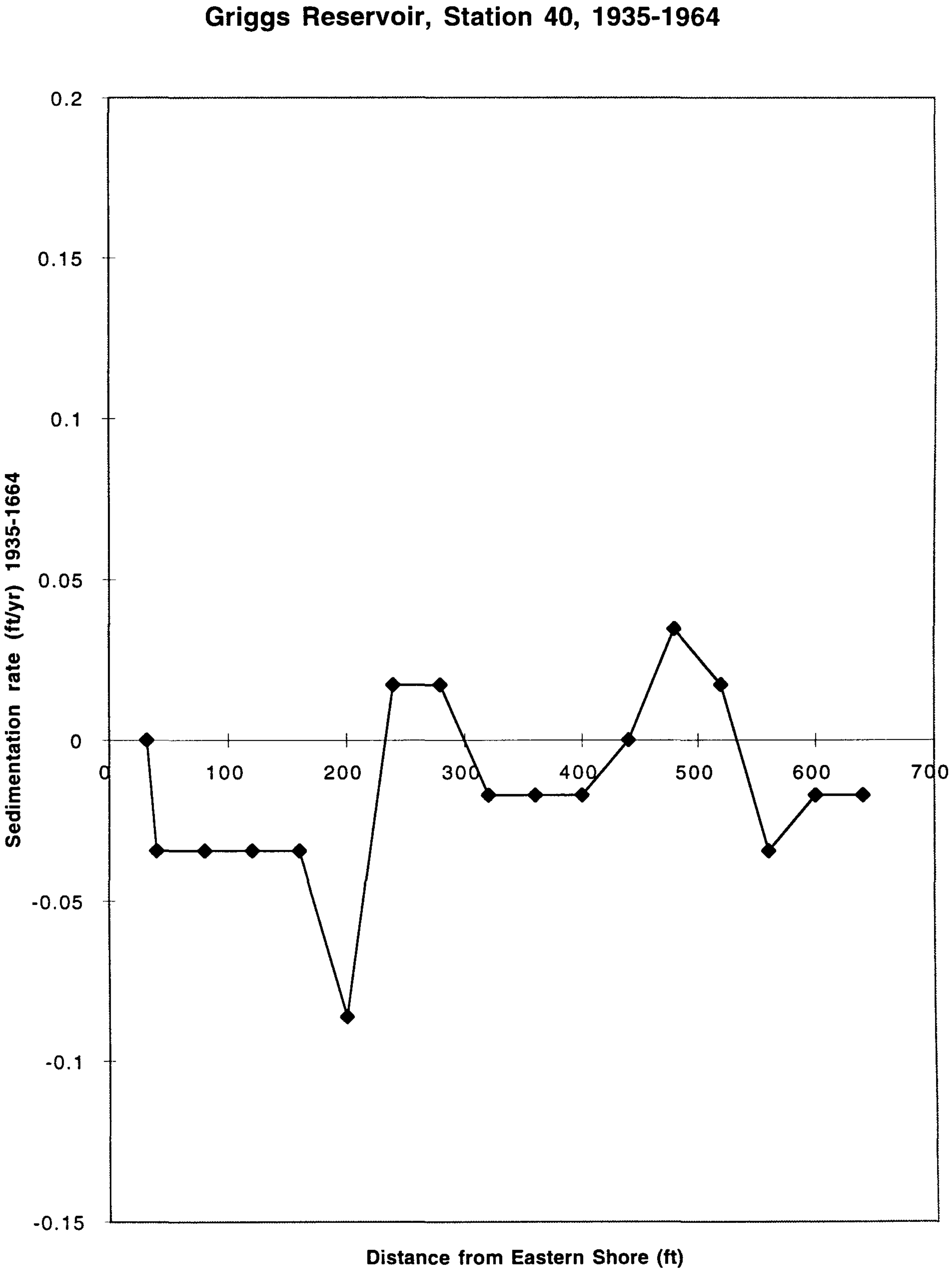

Griggs Reservoir, Station 6, 1935-1964
Sedimentation rate (ft/yr) 1935-1964
0.2
0.15
0.1
0.05
0
-0.05
0
100
200
300
400
500
600
700
Distance from Eastern Shore (ft)

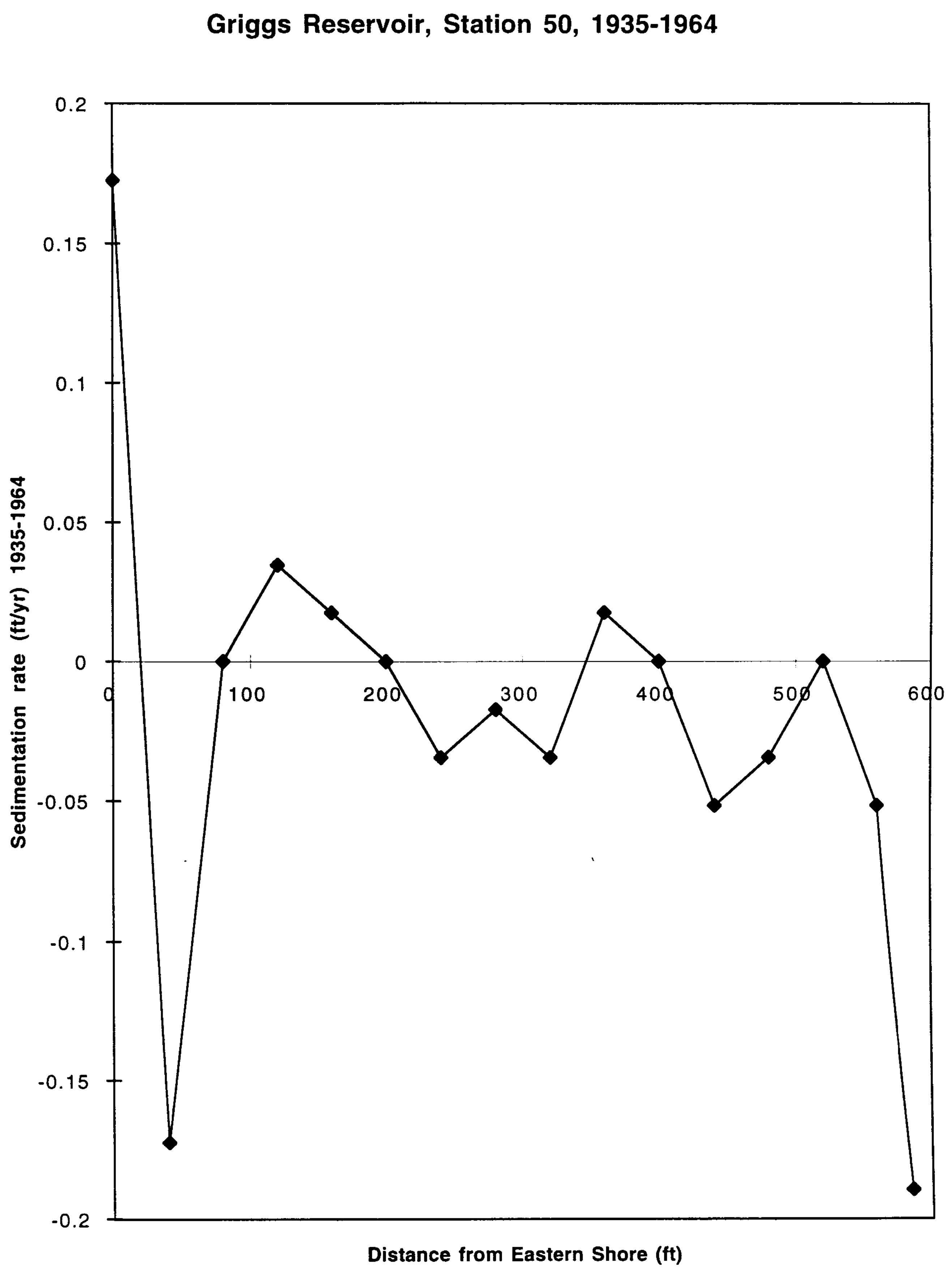
Griggs Reservoir , Station 10, 1935-1964



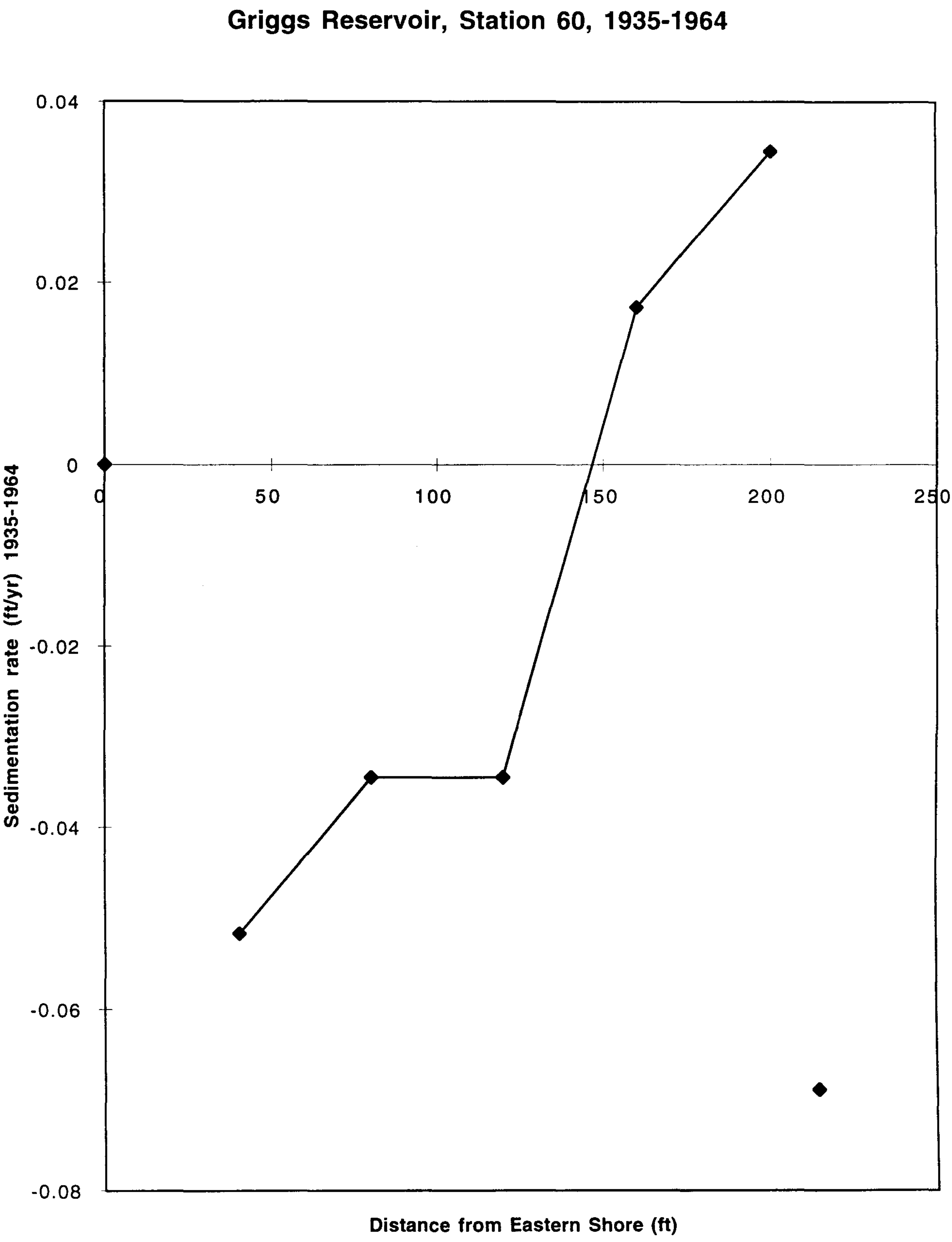

Griggs Reservoir, Station 20, 1935-1964
0.2
0.15
0.1
0.05
0
-0.05
Sedimentation rate (ft/yr) 1935-1964
0
50
100
150
200
250
300
350
400
Distance from Eastern Shore (ft)

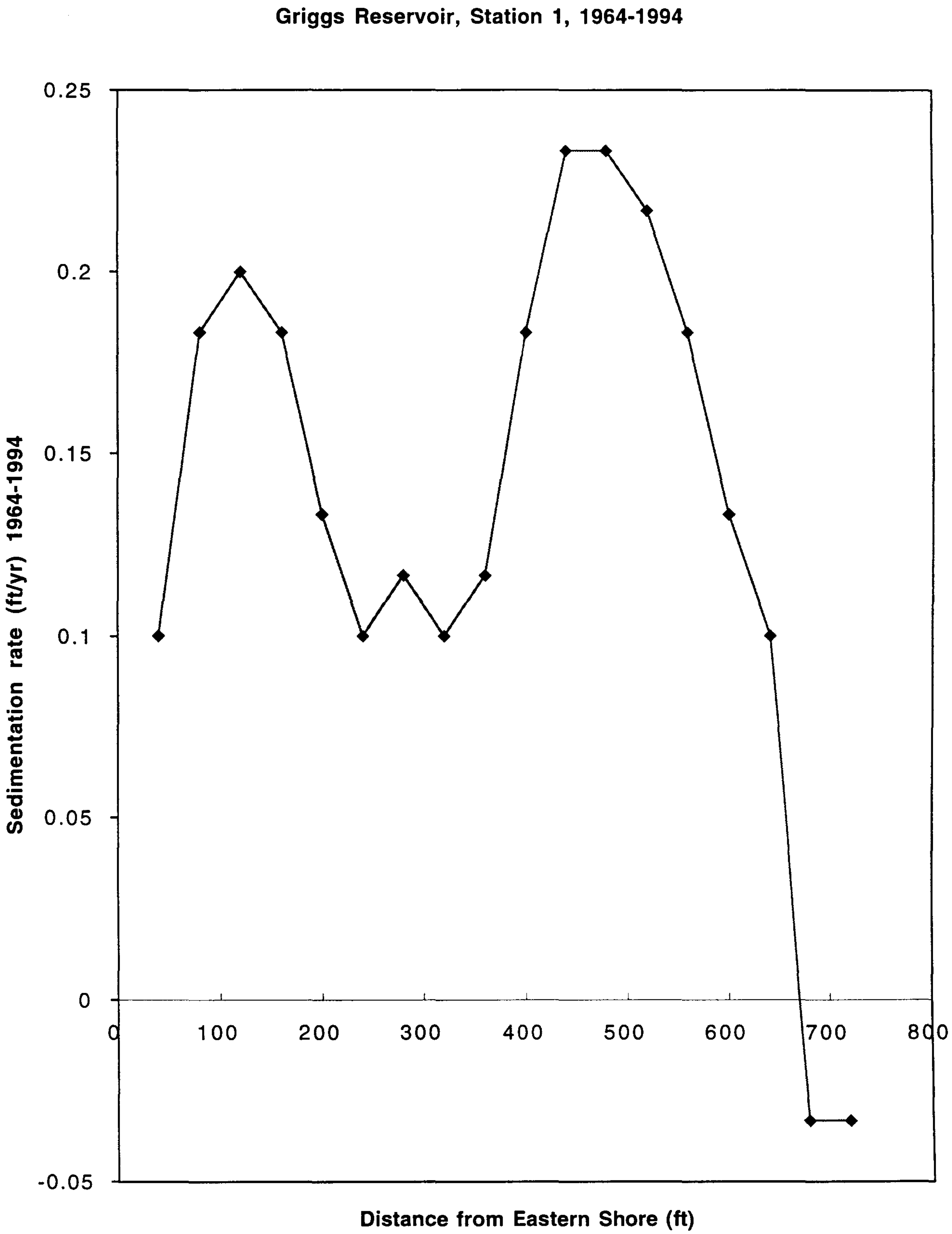

Griggs Reservoir, Station 30, 1935-1964
0.2
0.15
0.1
0.05
0
-0.05
Sediomentatiom rate (ft/yr) 1935-1964
0
100
200
300
400
500
Distance from Eastern Shore (ft)

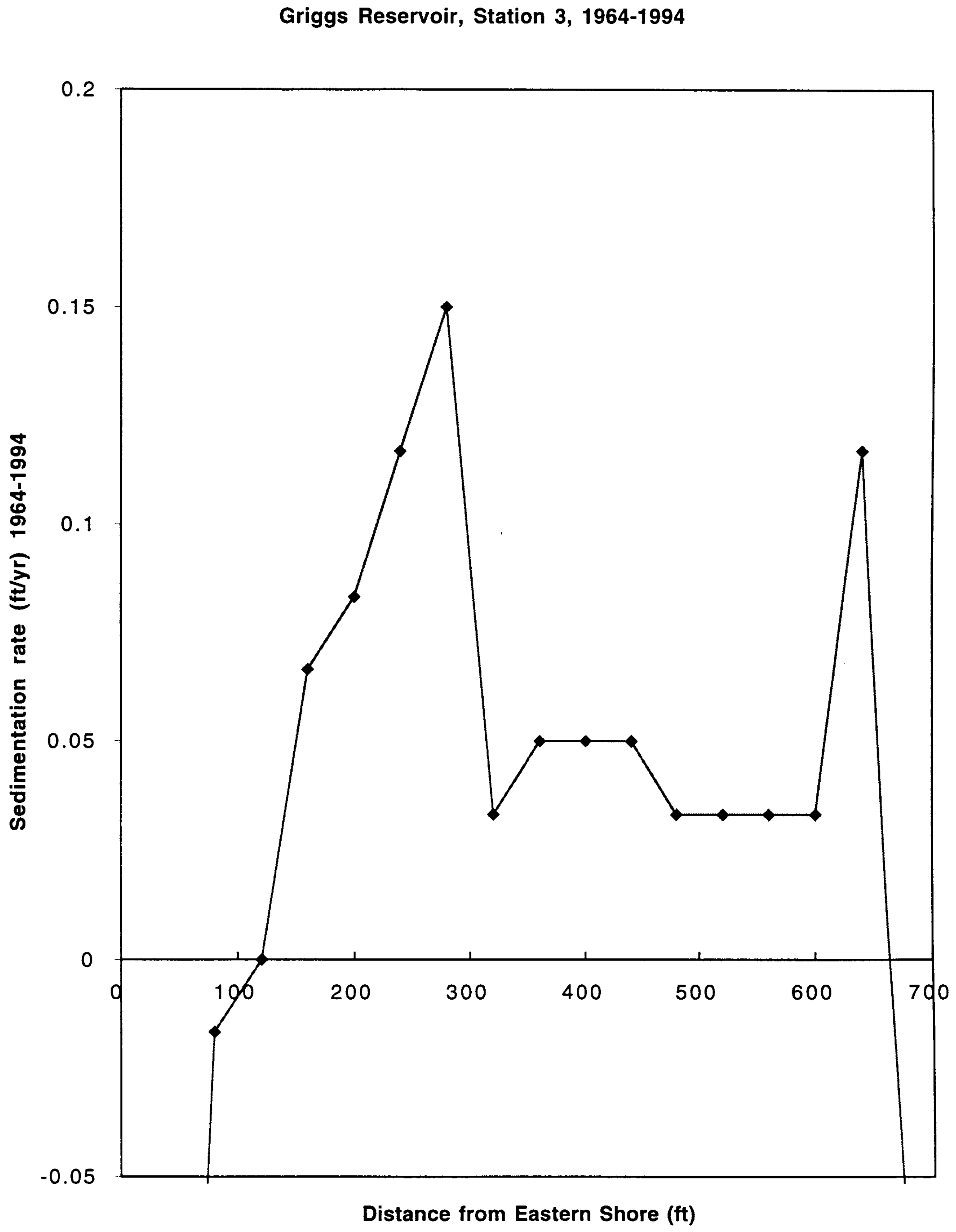

Griggs Reservoir, Station 40, 1935-1964
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
Sedimentation rate (ft/yr) 1935-1664
0
100
200
300
400
500
600
700
Distance from Eastern Shore (ft)

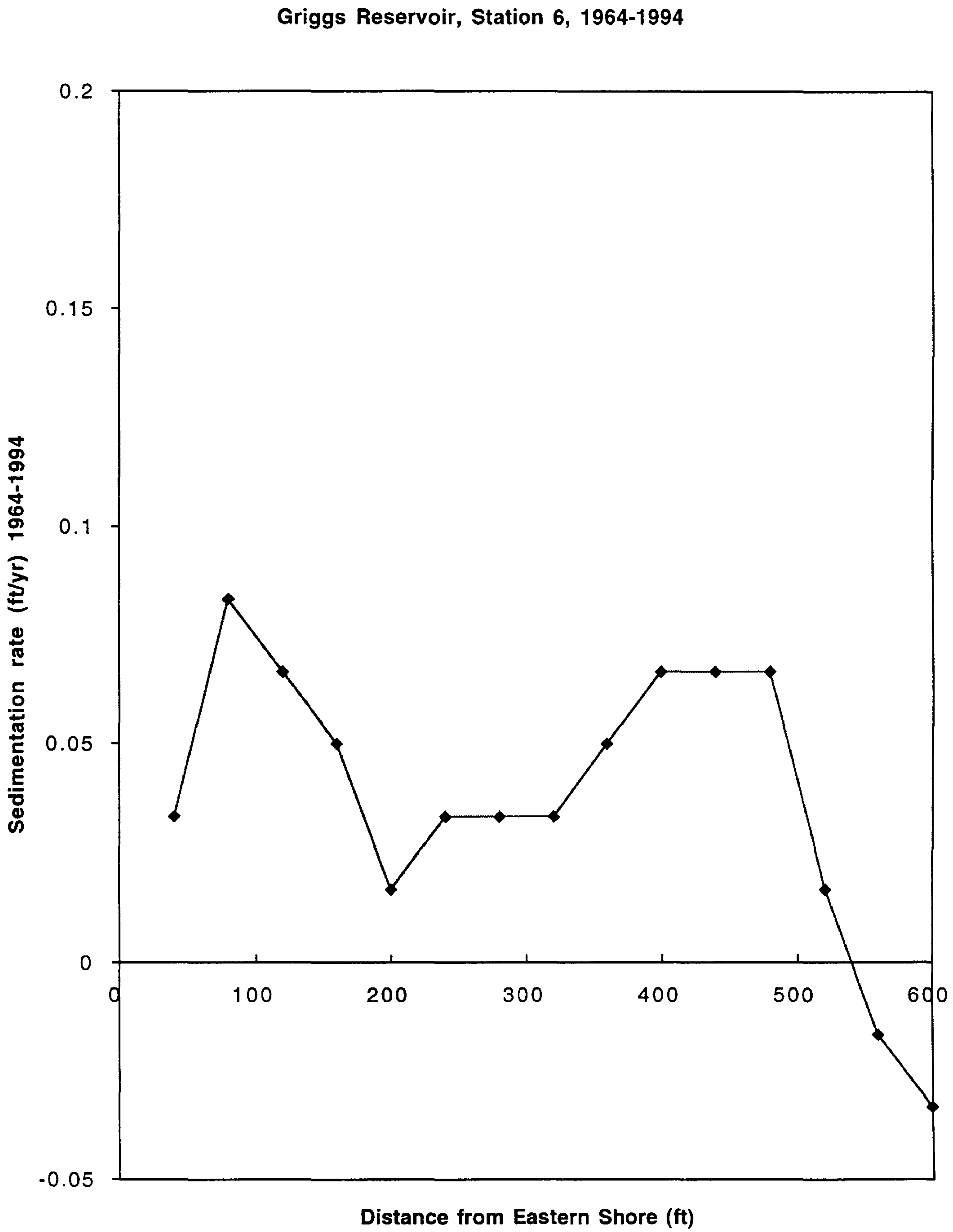


Griggs Reservoir, Station 50, 1935-1964
Sedimentation rate (ft/yr) 1935-1964
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
100
200
300
400
500
600
Distance from Eastern Shore (ft)

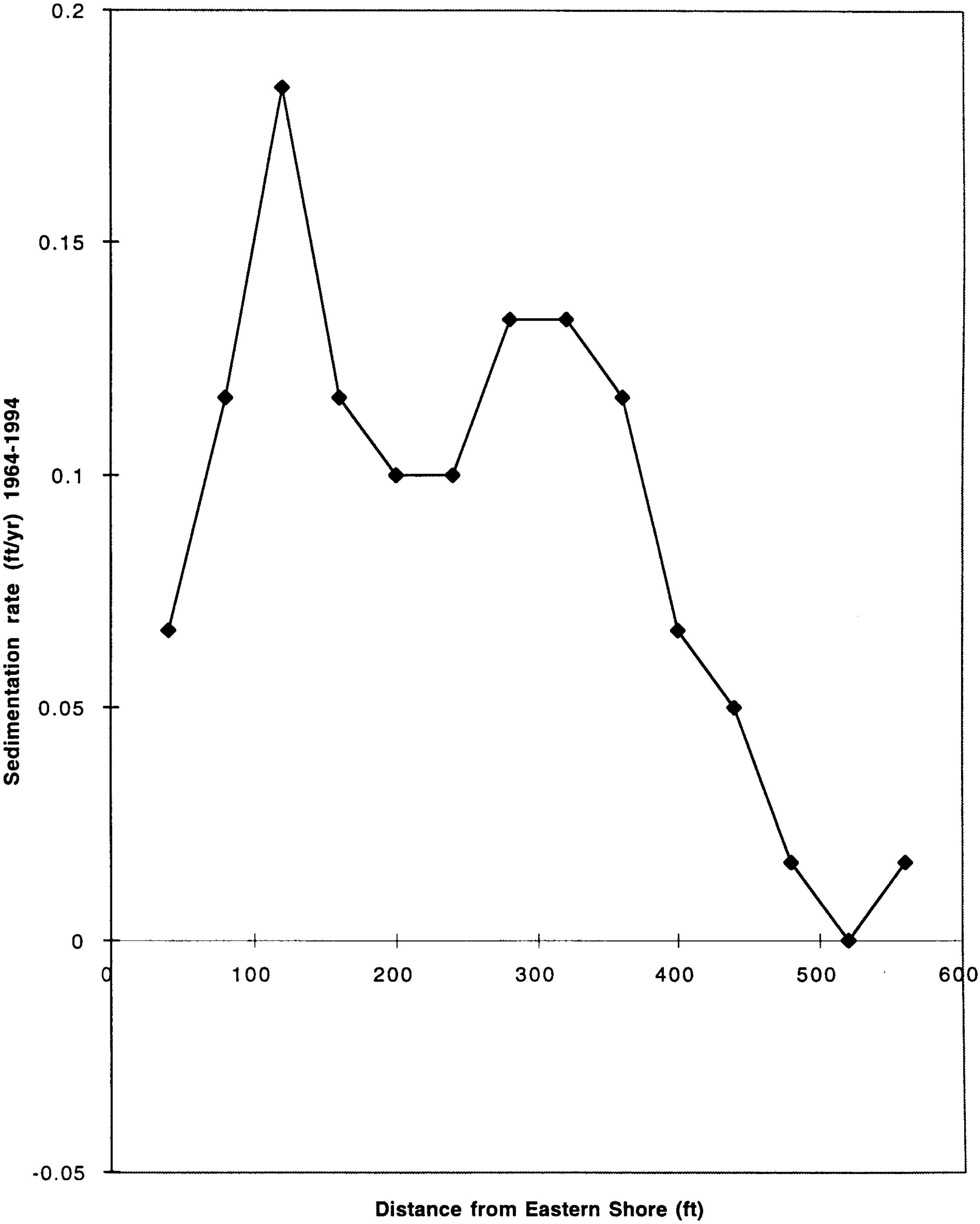

Griggs Reservoir, Station 60, 1935-1964
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
Sedimentation rate (ft/yr) 1935-1964
0
50
100
150
200
250
Distance from Eastern Shore (ft)


Griggs Reservoir, Station 1, 1964-1994
Sedimentation rate (ft/yr) 1964-1994
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
100
200
300
400
500
600
700
800
Distance from Eastern Shore (ft)

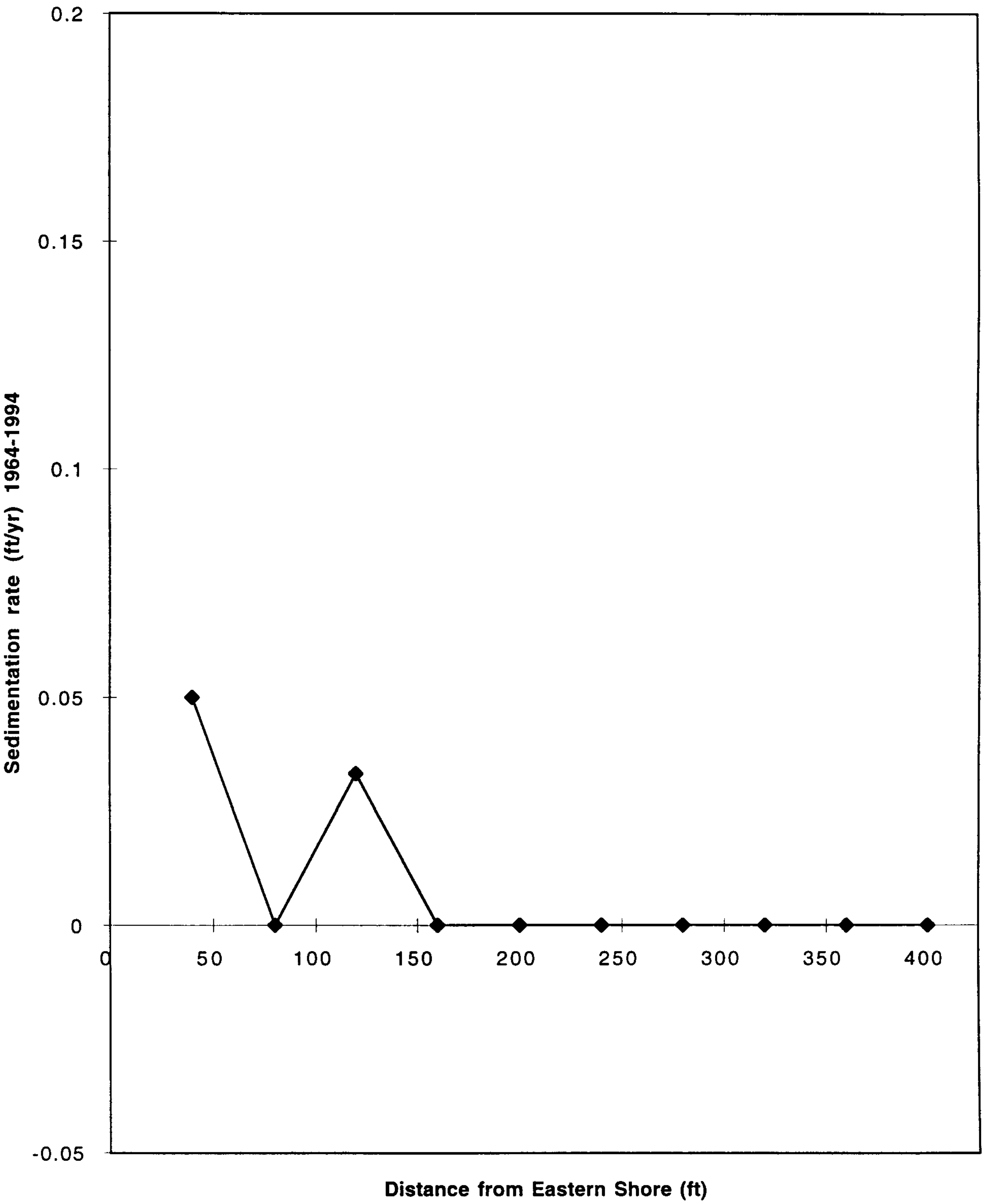

Griggs Reservoir, Station 3, 1964-1994
Sedimentation rate (ft/yr) 1964-1994
0.2
0.15
0.1
0.05
0
-0.05
0
100
200
300
400
500
600
700
Distance from Eastern Shore (ft)

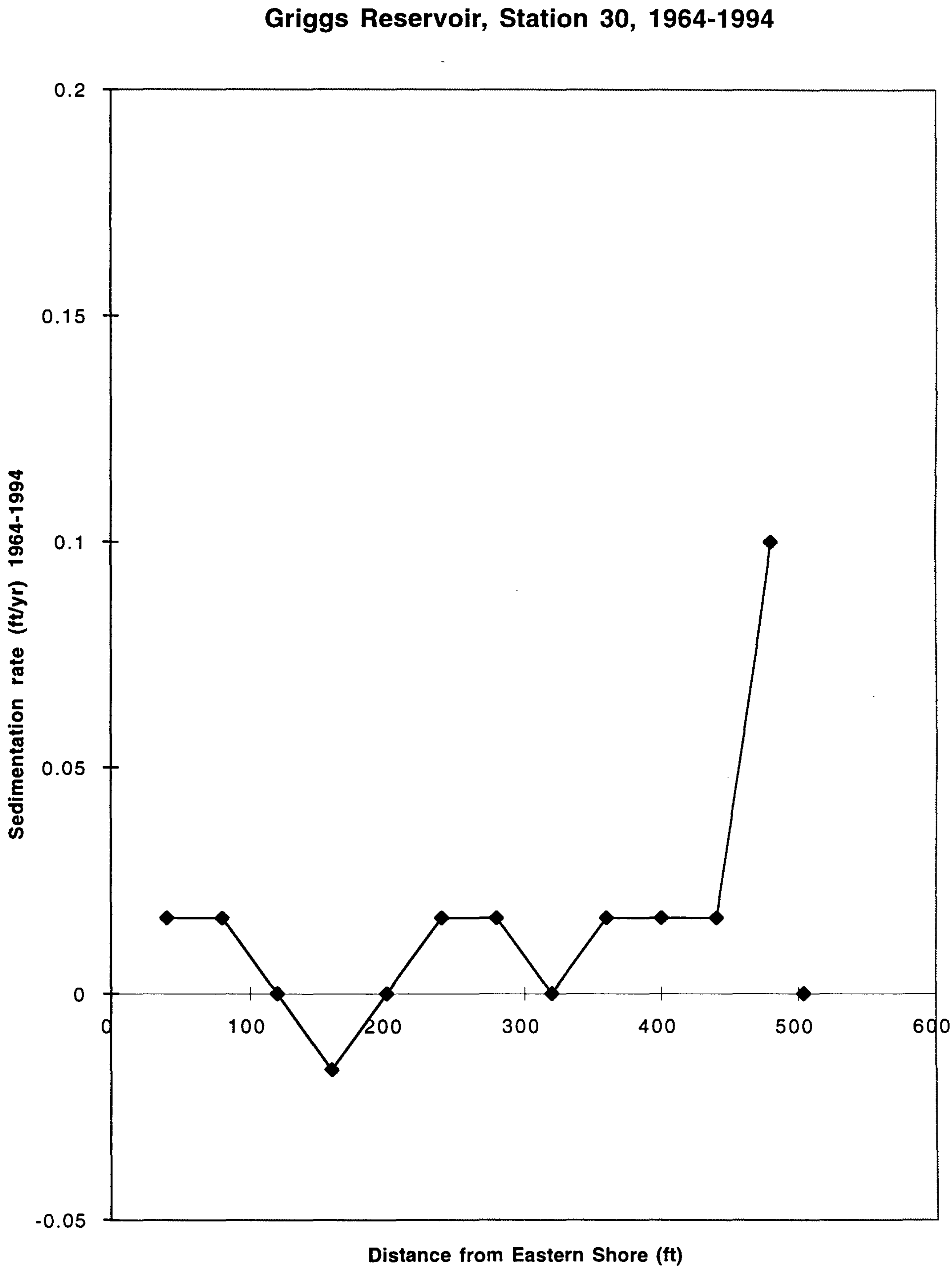

Griggs Reservoir, Station 6, 1964-1994
Sedimentation rate (ft/yr) 1964-1994
0.2
0.15
0.1
0.05
0
-0.05
0
100
200
300
400
500
600
Distance from Eastern Shore (ft)

Griggs Reservoir, Station 10, 1964-1994

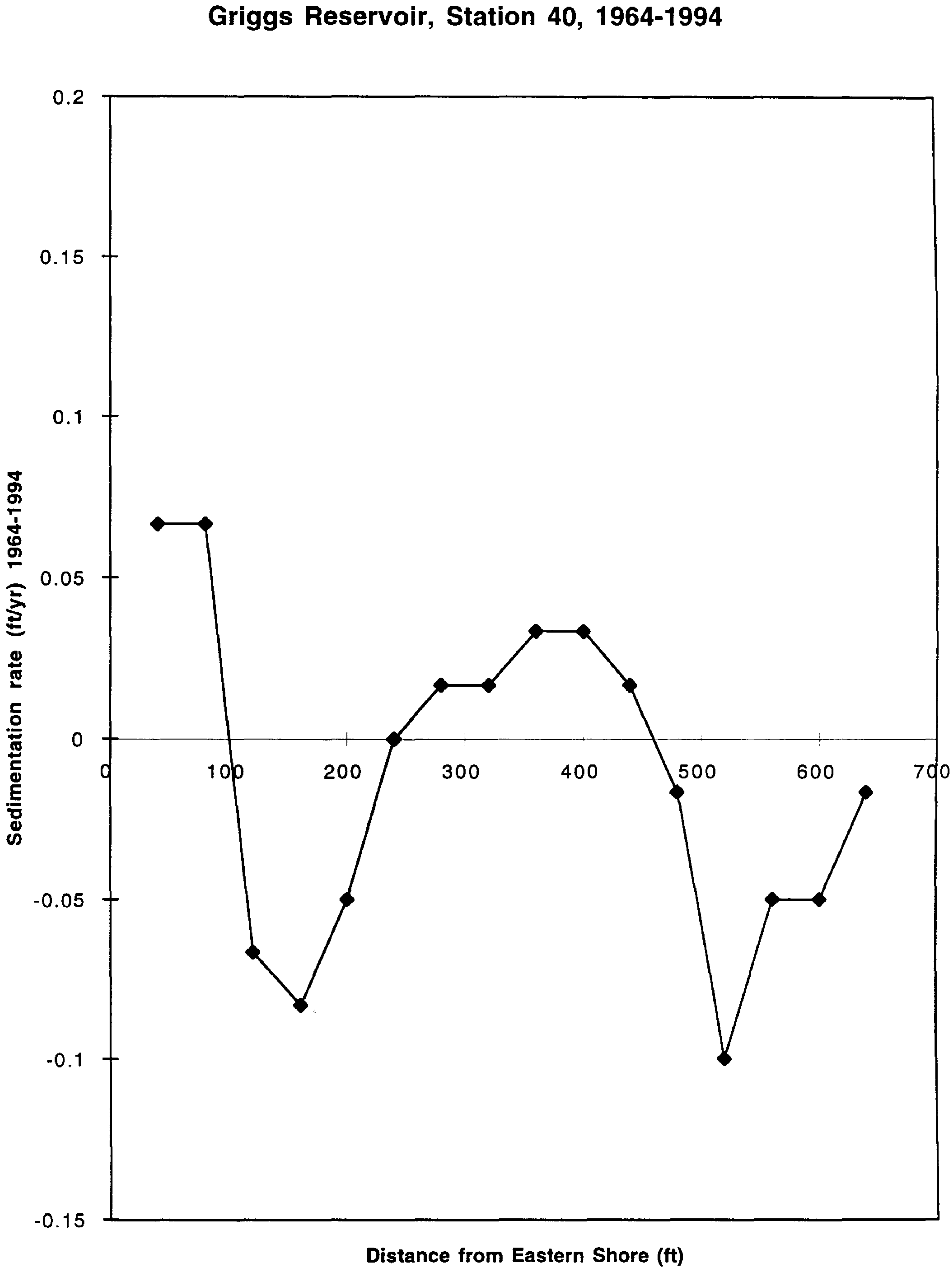


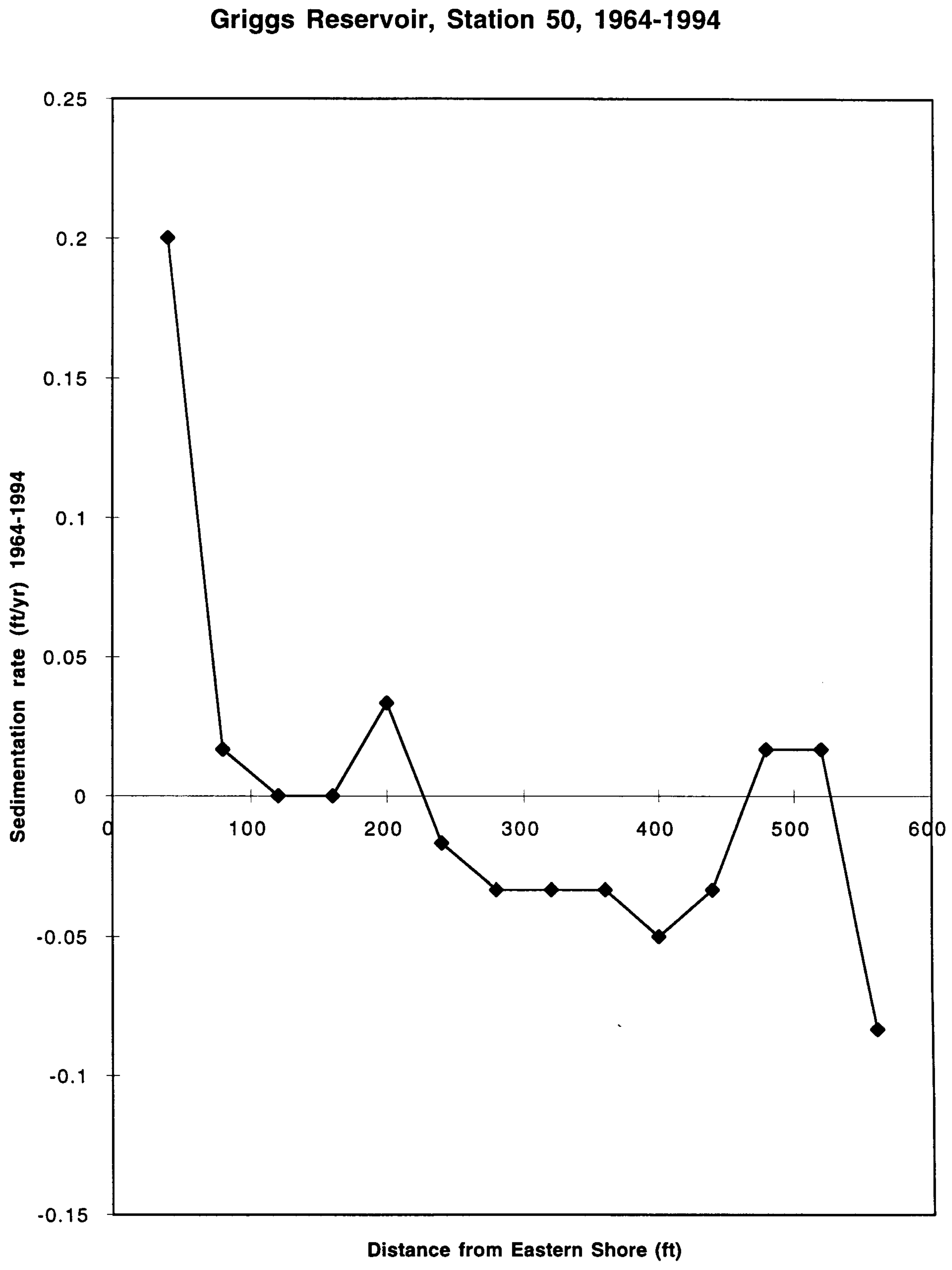
Griggs Reservoir, Station 20, 1964-1994





Griggs Reservoir, Station 30, 1964-1994
Sedimentation rate (ft/yr) 1964-1994
0.2
0.15
0.1
0.05
0
-0.05
0
100
200
300
400
500
600
Distance from Eastern Shore (ft)


Griggs Reservoir, Station 40, 1964-1994
Sedimentation rate (ft/yr) 1964-1994
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
0
100
200
300
400
500
600
700
Distance from Eastern Shore (ft)


Griggs Reservoir, Station 50, 1964-1994
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
Sedimentation rate (ft/yr) 1964-1994
0
100
200
300
400
500
600
Distance from Eastern Shore (ft)

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